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Initial Business Concept for the Neighborhood Data Center

Helsinki Metropolia University of Applied Sciences
Master's Degree

Industrial Management

Master's Thesis

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Preface

Thank you for reading this Thesis,

This Master's Thesis is purely a concept for one possible way to generate data center IT services, and this cannot be used as a general guide for building a green data center. The theory contains shortcomings, having some of those mentioned in relevant sections of this Thesis to eliminate the possibility of misunderstanding, some just purposely omitted to maintain the competitiveness of this intellectual property.

Generally speaking, this business concept's primary purpose is to boost discussion around environmental friendly data processing.

Sincerely yours,
Jyri Juvalainen
6 May 2016
Helsinki, Finland

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Generally used data center models do not support full energy re-use technologies very well. This new neighborhood data center business concept comes from the idea where all already used data center energy can be re-used for local community needs without district heat technologies. If all the energy used to operate the data center could be kept inside the neighborhood community, that would make a significant ecological difference to existing models. Moreover, it would help to reduce the global phenomenon of the environmental burden caused by data centers (Gartner. 2007; Greenpeace. 2014; Natural Resources Defense Council. 2015).

These currently used general data center models have gigantic units located usually away from the large cities and other dense population areas. Having this massive infrastructure located in one easy serviceable location create cost savings, but it also creates challenges to reuse the data center's energy efficiently for the needs of the society. In this Master's Thesis, the currently used general model has turned around by scattering this very large size unit into multiple very small units and these small nano size data center units are spread around to densely populated areas.

This Master's thesis is secondary research based on secondary data (Data 1) from existing knowledge on heating, water usage, energy costs and needs for a typical housing company in Finland. The second round data collection (Data 2) is for the data center technologies already in use, and the last round of data collection (Data 3) is performed to validate and support these results.

The outcome is the initial business concept for the neighborhood data-center business idea. This new concept brings for Giga-scale (very large scale) data center operators the possibility to have a new data center capacity with a minimal ecological footprint.

Keywords	Datacenter, Data Center, Nano data center, Energy Recycling, Neighborhood, Energy re-use, Sustainable Energy, Green Computing

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Explanations, Acronyms, and Abbreviations

Input	**Output**
Business Concept	A bridge between an idea and a business plan.
Carbon footprint	The amount of greenhouse gas emissions produced to support human activities often expressed as carbon dioxide.
Carbon-neutral	Not releasing carbon dioxide into the atmosphere or offsetting the amount of carbon dioxide emissions, for example, planting trees.
Cloud (computing)	The practice of using a network of remote data centers to manage, and process data, rather than locally.
Colocation, Colo	The data center where IT equipment, rack space, and network connections are available for rental to retail customers.
Data Center, Datacenter	A data center (sometimes spelled datacenter) is a centralized facility used to house computer systems and associated components. For example store data for business databases, social media content or online videos.
Economic Viability	To prove that project is economically feasible, innovative, sustainable and can support itself financially.
Fiber	Fiber optics, Optical- fibre or fibers are used to transmit light based communication between the two ends of the fiber cable. The fastest method of communication over long distances.
Giga-	SI unit prefix denoting a factor of a (short-form) billion. In this Thesis used to mean a very large data center. Refers to a data center's electricity consumption.
IT	Information technology, in this application prefix for computers and telecommunications equipment or related services.
kW	Kilo-Watt, SI unit of the power (W) multiplied with 1000 (1 kilo).
kWh	Unit of energy equivalent to one kilowatt (1 kW) of power sustained for one hour.
Mega-	SI unit prefix denoting a factor of a (short-form) million. In this Thesis used to mean a typical size data center. Refers to a data center's electricity consumption.

Input	Output
Micro-	SI unit prefix meaning one millionth. In this Thesis used to mean a small data center. This unit does not refer to a data center’s electricity consumption.
Nano-	SI unit prefix meaning one billionth. In this Thesis used to mean a very small data center. This unit does not refer to a data center’s electricity consumption.
Network	A computer network combines fibers and switches with servers. On a large scale creates the Internet.
Power Factor	In AC circuits, the power factor is the ratio of the real power used to do the work. For example, the resistive load has power factor 1.
PUE	Power usage effectiveness measures how efficiently a computer data center uses energy. Facility energy divided with IT equipment energy.
Server	Components inside data centers, usually servers are serving a certain purpose, for example, email server. Gigantic data centers typically host tens of thousands servers.
Switch	The network switch, a device that connects devices together on a computer network.
42U	42 rack units. The rack unit is standardized (SDO. EIA-310-D. 2005) height and width unit for rack mounted equipment. 42U is typically one full 187cm high rack used in a traditional data center environment.

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1 Introduction

The introduction contains an explanation of the business idea, Thesis objective, and the outcome, also including a description of the Thesis structure.

1.1 Business Idea

Neighborhood data center is an idea of having small size data centers locally next to the customers, instead of gigantic centralized data centers located far away from population centers. Similar size of data centers is known already in an industry as nano or micro data centers.

When the data center is located next to the customer, service speeds are greatly faster and also heat energy created by data center can be directly re-used by a local community. The great difference to typical data center energy re-use methods is that energy re-users are directly next to original heat source, without a need to use of any district heat transfer networks.

This kind of energy saving method makes a significant difference in data center carbon footprint.

1.1.1 Traditional Data Center Model

Current traditional data center models (Image explaining later on) have large units usually located away from major cities and other dense population areas. Having this massive infrastructure located in one easy serviceable location creates cost savings, but it also creates challenges to re-use the data center's energy efficiently for the needs of the society. (Data Center Knowledge. 2010; Forbes. 2015; SAP SE. 2016)

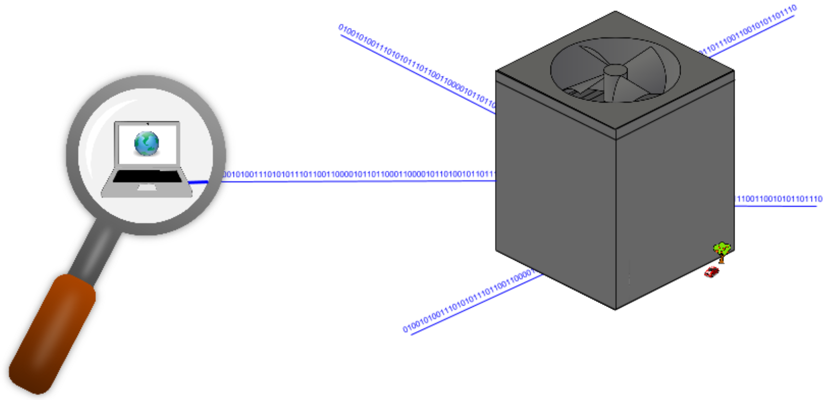

Image 1. Simplified home computer and data center relation

The Image above shows a very simplified model where personal devices connect to centralized data centers, creating possible service related energy loss happening in this single point.

Generally speaking, data centers need the energy to keep servers and communication switches inside data center computing and serving data center customers. In the form of optical fiber, light is the only energy which exits from the data center back to the client, consuming all other energy in the data center. In simple terms, this means converting almost all energy supplied to the data center into heat inside the center. Energy is typically bound to the air or water. In some cases, energies can be temporarily stored in thermal or electrical batteries (Zheng, Ma, Wang. 2015, Miller. 2009; Wikipedia. 2016).

There are multiple studies on data center energy efficiencies
(Glanz, J. 2012; Natural Resources Defense Council. 2014; Obaidat, M., Anpalagan, A. and Woungang, I. 2012). Also, the amount of energy used to run the Internet is starting to looking challenging for a modern way of thinking about a green and sustainable industry (Gartner. 2007; Greenpeace. 2014; Natural Resources Defense Council. 2015).

1.1.2 Neighborhood Data Center Business Concept

The proposed, new concept turns the currently used general data center model around by scattering the gigantic unit into multiple tiny units and by spreading these units to densely populated areas. These small, nano-sized data center units are so-called neighborhood data centers. "Neighborhood data center business concept" is taking a new point of view for data center energy recycling. The main idea is to re-use all of the data center's wasted energy for local community needs. If there would be a possibility to re-use all the energy used to operate the data center inside the neighborhood community, it would make a significant ecological difference comparing to the existing data center models. Naturally, this would help reduce the global phenomenon of the environmental burden caused by data centers. Illustrated in the next Image.

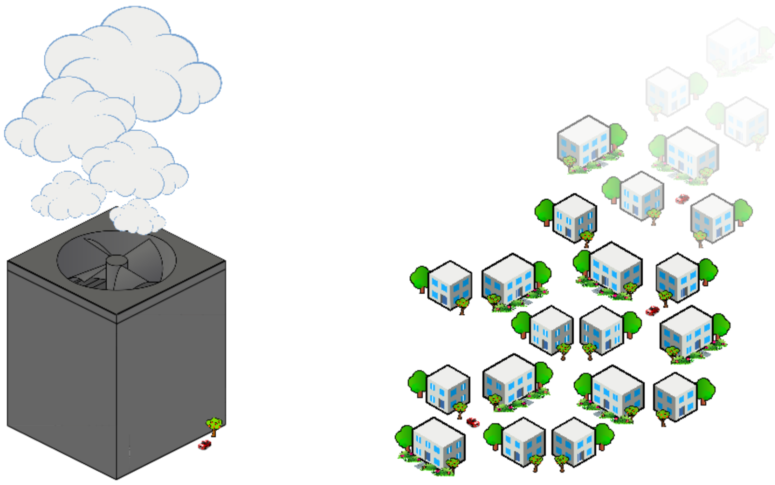

Image 2. Centralized data center compared to scattered neighborhood data center model.

In the Image above, there is a comparison of a gigantic data center evaporating heat and multiple small data centers keeping all the excess energy inside data center structures.

Current business models do not show any benefits to scattering gigantic data centers to these little units, except faster service response times. This Thesis brings a new perspective to current models by adding the energy recycling factor.

If locating data centers in places where all energy used for data center operations can be collected or re-used without complicated energy transfer solutions, the model of these small data centers starts to sound much more attractive.

1.2 Objective and Outcome

The main objective is to develop an initial business concept for the neighborhood data center. This main purpose practically comes from the secondary objective, however, due to current economic reasons, the main objective has to be a profitable business. Leaving the secondary objective more or less just to support the main purpose.

The secondary objective, which as said will be self-involved, is helping readers to mind the challenges of the future environmental friendly data center computing. Under the circumstances this should contribute to reducing the global phenomenon of the environmental burden caused by data centers (Gartner. 2007; Greenpeace. 2014; Natural Resources Defense Council. 2015). In these referenced studies and presentations is brought concerns about the continued growth of data centers to be as one of the world's largest industrial energy consumer, and when combining with the absence of energy efficient recycling, possibly affecting negatively to our living environment.

The outcome of this Thesis is initial neighborhood data center concept for a further product and service development. This proposal will mainly contain parts how the business model can be built around this concept and also create base data for next concept development steps.

1.3 Structure of Thesis

This Thesis contains seven main parts. The first part is used to introduce the topic, and also explain the opportunity of this new business concept. The second part presents the chosen research design and explains used data collection methods. After this, the third section introduces conceptual framework and gives literature review of business models and concept development used for this Thesis.

The fourth part the data is analyzed in order to build a base for the neighborhood data center. In section five, the data center infrastructure is located on this building base created in section four. Section six focuses on the concept, and section seven is reserved for discussion and conclusions. After these two last parts, the concept is ready for further development.

The next section explains the methods and materials used in this Thesis.

2 Method and Material

This section goes through the research and data collection methods used in this Thesis. It starts with explaining the chosen model through a research design diagram and after that moves to the data collection methods.

2.1 Research Design Diagram

Using the chosen sequential development process model introduced in the later section, the research design diagram of this Thesis is an enlarged version of the first steps of the traditional sequential development process. This diagram is illustrated in the Image below.

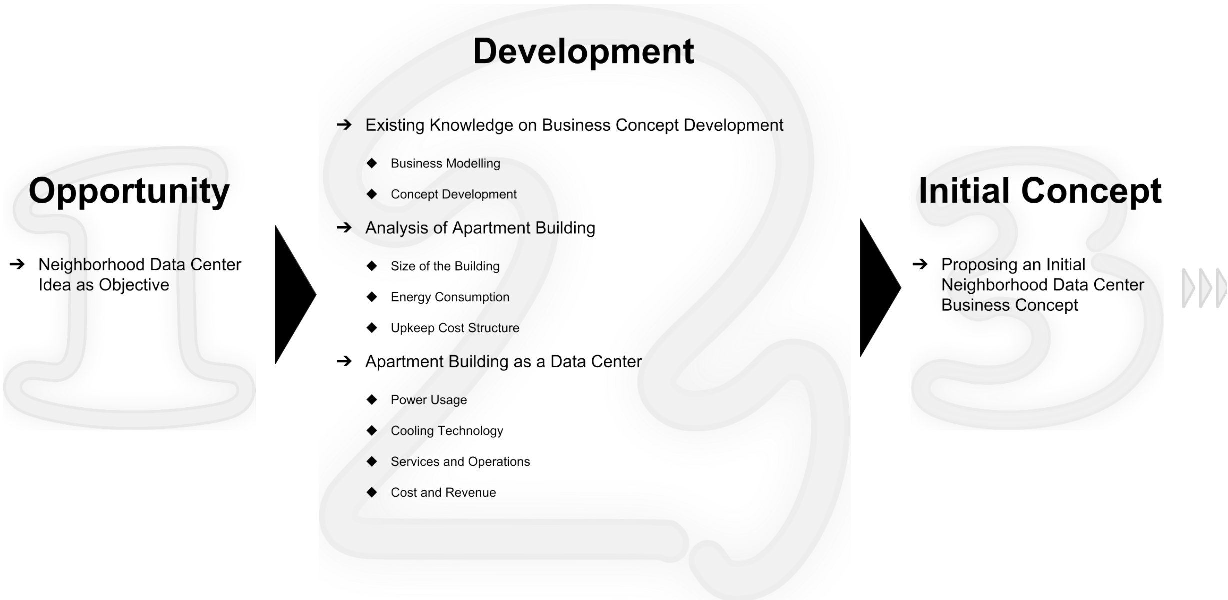

Image 3. Thesis research design diagram

The Image shows steps named as step 1, step 2 and step 3. Step 1 is identifying opportunity, in this case, it is the idea of creating new data center concept that supports energy re-use in the neighborhood.

Step 2 is the most laborious part of this Thesis, i.e. developing the actual neighborhood data center concept. This is done through secondary data collection, collecting together data center knowledge articles, books, and public online databases. In step 3, all this is put together to have the initial prototype concept with reviews and conclusions based on the results. This initial business concept is an outcome of this Thesis and the new concept is ready for further development.

2.2 Data Collection Plan

The data collection for this Thesis is done mainly from statistical secondary data sources, technical data center online literature, and expert comments and views about the industry. The whole data center industrial sector is new; this brings a challenge that only limited amount of data is available in a public book or academic format. Because of this, when collecting data from controversial or untrustworthy sources for this Thesis, most of the data sources are doubled or even tripled.

As the amount of data collected for this study comes from many different sources, it was impossible to get all the information on one page only. Thus, the data collection is shown in the Table which extends over the next few pages.

The Table below shows the list of data used in this Thesis.

Data type	Source	Topic/ description	Created/ accessed	Type of data	Vol.
Data 2	AST Modular	Cointainerized Data Centers	2016 19-Mar-2016	Technical document	3 p.
	• Used as a source for existing technical design				
Data 2	Avelar, V., Azevedo D., and French, A.	PUE: A comprehensive examination of the metric	2012 20-Mar-2016	Technical document	83 p.
	• Used as a source for existing technical design				
Data 2	CloudPing.info	Estimate the latency from your browser to each AWS region	2016 20-Mar-2016	Technical article	1 p.
	• Used as a source for existing technical design				
Data 2	Edwards, J.	New technologies mean shorter server life cycles	2010 20-Mar-2016	Technical article	1 p.
	• Used as a source for existing technical design				
Data 1	Energy Authority	Verottomat nimelliset kokonaishinnat	2016 28-Mar-2016	Statistical information	1 p.
	• Statistical data used to create the adapted data Table				
Data 2	Folger, J.	The pros and cons of automated trading systems	2016 19-Mar-2016	Technical article	3 p.
	• Used as a source for existing technical design				
Data 2	Golinska, P. and Kawa, A.	Technology management for sustainable production and logistics	2015 Mar-2016	Technical book	219 p.
	• Used as a source for existing technical design				
Data 1	Helsinki Region Infoshare	Helsingin seudun asuntokuntien pinta-ala	2016 04-Mar-2016	Statistical information	1 p.
	• Statistical data used to create the adapted data Table				

Table 1. Data collection table

Data type	Source	Topic/ description	Created/ accessed	Type of data	Vol.
Data 2	ICO, Information Commissioner's Office	Sending personal data outside the European economic area	2016 19-Mar-2016	Official information	18 p.
	● Used as a source for existing technical design				
Data 2	IEC, International Electrotechnical Commission	Standard for plugs, sockets and couplers	1999 Mar-2016	Official information	181 p.
	● Used as a source for existing technical design				
Data 3	Informant 1.	Data centers and environment	29-Jan-2016	Interview	2 p.
	● Used as a source for existing technical knowhow				
Data 2	Kaysenmay, R.	Off the grid living in Brooklyn	2012 20-Mar-2016	Newspaper article	3 p.
	● Used as a source for existing technical design				
Data 2	Kent, P.	Improve cloud latency and throughput	2015 20-Mar-2016	Technical article	3 p.
	● Used as a source for existing technical design				
Data 2	Koomey, J. and Taylor, J.	30 percent of servers are comatose	2015 20-Mar-2016	Case study	3 p.
	● Used as a source for existing technical design				
Data 2	Miller, R.	Air cooling vs liquid cooling	2009 11-Mar-2016	Technical article	1 p.
	● Used as a source for existing technical design				
Data 2	Miller, R.	Cooling servers with waste water	2014 05-Apr-2016	Technical article	1 p.
	● Used as a source for existing technical design				

Table 1. (Continued from the previous page) Data collection table

Data type	Source	Topic/ description	Created/ accessed	Type of data	Vol.
Data 2	Minas, L and Ellison, B.	Energy efficiency for information technology	2015 04-Mar-2016	Technical article	18 p.
	• Used as a source for existing technical design				
Data 1	Motiva Oy	Lämmönkulutus	2015 04-Mar-2016	Statistic document	1 p.
	• Statistical data used to create the adapted data Table				
Data 1	Motiva Oy	Vedenkulutus	2015 04-Mar-2016	Statistic document	2 p.
	• Statistical data used to create the adapted data Table				
Data 2	Motiva Oy	Vesikiertoinen patterilämmitys	2013 05-Apr-2016	Technical article	1 p.
	• Used as a source for existing technical design				
Data 1	Official Statistic of Finland (OSF)	Buildings and free-time residences	31-Dec-2014 12-Feb-2016	Statistic document	1 p.
	• Statistical data used to create the adapted data Table				
Data 1	Official Statistic of Finland (OSF)	Dwellings and housing conditions	31-Dec-2014 12-Feb-2016	Statistic document	1 p.
	• Statistical data used to create the adapted data Table				
Data 1	Official Statistic of Finland (OSF)	Asunto-osakeyhtiöiden talous	31-Dec-2014 12-Feb-2016	Statistic document	2 p.
	• Statistical data used to create the adapted data Table				
Data 2	Palo Alto Networks, Inc.	What is a data center?	2016 10-Mar-2016	Technical article	2 p.
	• Used as a source for existing technical design				
Data 2	Quora, Inc.	How many amps are needed for a rack of servers	2011 04-Mar-2016	Technical article	1 p.
	• Used as a source for existing technical design				

Table 1. (Continued from the previous page) Data collection table

Data type	Source	Topic/ description	Created/ accessed	Type of data	Vol.
Data 2	RapidTables.com	Power factor	2016 20-Mar-2016	Technical article	1 p.
	● Used as a source for existing technical design				
Data 2	Rouse, M.	Power usage effectiveness	2009 20-Mar-2016	Technical article	1 p.
	● Used as a source for existing technical design				
Data 2	SAP SE	How data center works	2016 11-Mar-2016	Technical article	12 p.
	● Used as a source for existing technical design				
Data 2	Scalet, S.	How to build physical security into a data center	2015 19-Mar-2016	Technical article	4 p.
	● Used as a source for existing technical design				
Data 1	Statistical Yearbook of Finland	Statistical data from Finland	2014 20-Mar-2016	Statistic document	662 p.
	● Statistical data used to create the adapted data Table				
Data 1	Sähköinfo Oy	Suomen sähköhinta	2010 28-Mar-2016	Statistic document	1 p.
	● Statistical data used to create the adapted data Table				
Data 1	Talokeskus Yhtiöt Oy	Kiinteistöhoitokulut, As Oy Kerrostalot koko maa 2011	2011 02-Jan-2016	Email document	1 p.
	● Statistical data used to create the adapted data Table				
Data 2	Uptime Institute	Data center industry survey	2014 04-Mar-2016	Technical document	15 p.
	● Used as a source for existing technical design				
Data 1	Valtion Ympäristöhallinto	Energiankulutus asuinkerrostalossa	- 04-Mar-2016	Official document	1 p.
	● Statistical data used to create the adapted data Table				

Table 1. (Continued from the previous page) Data collection table

Data type	Source	Topic/ description	Created/ accessed	Type of data	Vol.
Data 1,2	Virta, J and Pylsy, P.	Taloyhtiön energiakirja	2011 04-Mar-2016	Book	192 p.
	● Used as a source for existing technical design				
Data 2	Whitmore, G.	Water cooled solutions	2014 05-Apr-2016	Technical document	1 p.
	● Used as a source for existing technical design				

Table 1. (Continued from the previous page) Data collection table

2.3 Reliability and Validity Plan

Reliability in research means that the used data is stable, consistent and inherently repeatable. Validity, in turn, explains how data and results meet scientific requirements. In other words, how data measures what it should measure.

This Thesis relies mainly on publicly available data, and data reliability can be even better with public data. However, like also mentioned in the previous subsection, the limited amount of available data bring some data validity problems. One reason to enhance this comes from the point that objective cannot be solidly framed from the beginning, and minor changes in the object interpretation can change needed data type to entirely different kind.

A method of using as many sources as possible and giving higher weight for data based on physics, stats or calculations, data reliability and validity can be kept on the acceptable scientific level. However, maintaining an eye on the level of data validity all the time is necessary. This prevents data validity from sliding to feeling-based data.

3 Existing Knowledge on Business Concept Development

In this section, it is studied what kind of methods is available for business concept development. Including tools for business modeling and general concept development. Collecting outcome to the conceptual framework in last subsection.

3.1 Business Modelling

Every business needs a working business model, and when simplified, business model "refers to the logic of the firm, the way it operates and how it creates value for its stakeholders" (Casadesus-Masanell and Ricart. 2010).
The following sub-sections focus on investigating what a business model is, what kind of models can be used and how to adapt into those models presented in this Thesis.

3.1.1 Purpose of the Business Model

Michael Lewis explains business model to be "a term of art" (Lewis. 1999). It means that challenge with the business model is that there is no right and ready model to pick up. Moreover, it all depends on how you are going to use that chosen business model (Ovans, 2015). This view is supported for example in Zott, Amit and Massa's article about business model concept controversies between different scholars (Zott, Amit, and Massa. 2011). Therefore, in this Thesis, it is not needed try to find the best business model. The focus is to explain basic business modeling and use that knowledge to support the construction of this Thesis.

3.1.2 White Space Model

The first business model discussed is the white space model, it is not exactly a business model at all, it is a tool to understand the need for business model renovating. The model is added to make easier to realize the dimensions of the business model to this Thesis.

Quite often when creating something new, it is harder to use already existing business model. One way to explain this is to use a term called white space. White space means that business is moving to the so-called uncharted territory. Doing something so new or different for that business that existing models just don't work with this new concept. The white space model also assumes that this new business opportunity is so juicy that even though knowledge of this specific business is low and the conditions to run this new business is against existing core business, there is still interest in jumping into this new challenge. (Johnson. 2010)

In the following Image, it is explained how white space fits into an existing core business model.

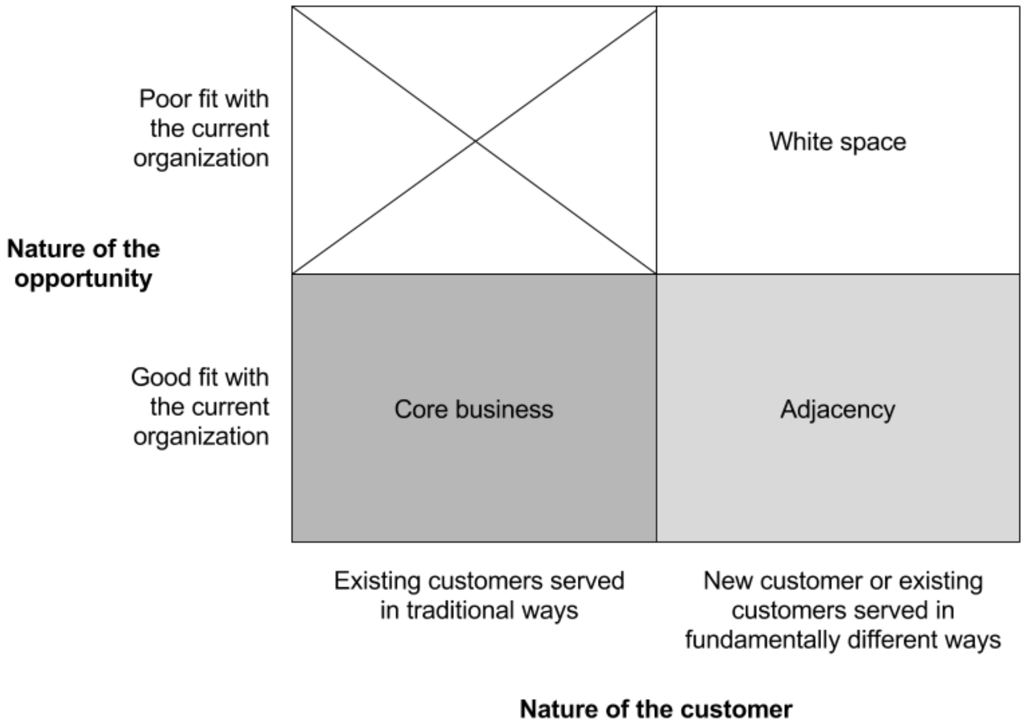

Image 4. Defining the white space (Johnson. 2010)

In the previous Image, where core business is located in the lower left corner, white space is located at the upper right corner. This kind of contrast predicts poor fit with the current organization structure, but at the same time, it shows potential new customers or happier existing customers.

The term white space does not solve or give needed business model. In this Thesis, it can be used more to explain the challenges of choosing the right business model in a case where is existing business model for profitable business, but there is a need to change something so dramatically that this old business model cannot be used directly to support and justify this new business opportunity.

3.1.3 Four Key Elements Model

One of the simplest business models is the four key elements model presented by Mark W. Johnson (Johnson. 2010), starting from the basics. This model is explained in the following Image.

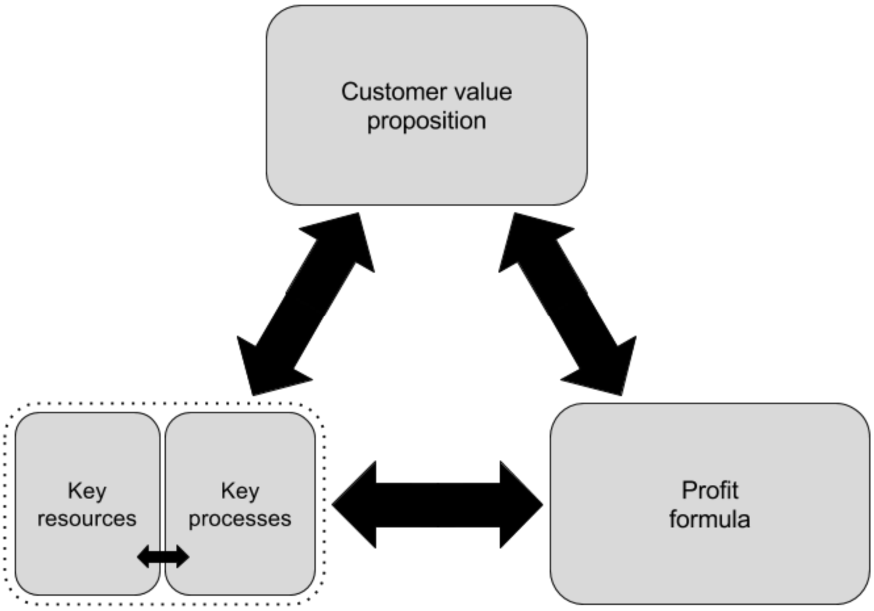

Image 5. The four-box business model (Johnson. 2010)

In the Image showing the four-box business model, there is strong customer value proposition on top of everything. That is something that someone is ready to pay money for. The second important element is profit formula, the method how the company can collect value in the form of profit. Last third and fourth box are key resources. These are the tools how a company will create customer value and the profit. These can be, for example, skills, working methods, and critical assets the company has.

3.1.4 Business Model Canvas

Alexander Osterwalder has created a practical tool called Business Model Canvas including nine building blocks to set up and test business models (Osterwalder. 2013). This canvas model is presented in the Image below.

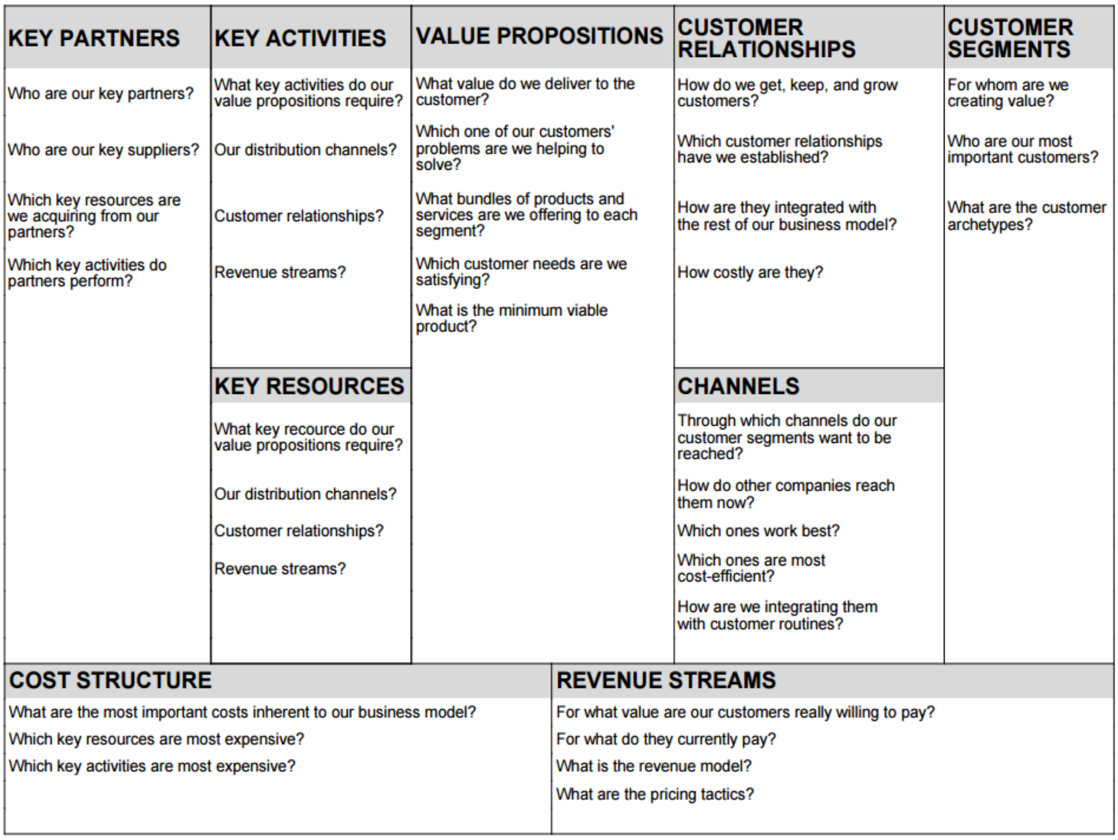

Image 6. The business model canvas (Osterwalder. 2013)

In the business model canvas Image, there are key elements located next to each other with a logical sense. There is easy to find traditional elements of a good business model but enhanced with series of hypotheses. When creating new or testing old business model, the business key elements are placed onto this canvas and challenged with the chosen questions. (Osterwalder. 2013) Osterwalder's canvas model is created to help move out from traditional product-centric thinking and moving along to business model thinking (Osterwalder. 2013).

Next, available concept development methods are presented.

3.2 Concept Development

Product development programs have been studied by Schilling and Hill (Schilling and Hill. 1998). Concept development can be done traditionally using linear steps or using time more efficiently with overlapping developing techniques. Starting from the traditional models, in the following Image is presented Toll's checklist based sequential approach with headings.

1. Planning (including identification of company assets, formulation of objectives) and broad definition of markets of interest;
2. Market exploration (including identification of potential growth areas) and existing products;
3. Search for product ideas;
4. Investigation of new ideas in terms of company resources and abilities;
5. Evaluation of new ideas (including concept and product testing);
6. Selection of remaining favourable ideas based on financial considerations;
7. Implementation of test marketing and/or national launch.

Image 7. The development process described by Toll (Toll. 1969)

Toll’s process, in the previous Image, has very traditional and logical steps for a new product launch, having a clear step by step checklist approach for driving the project through successfully. The similarities are clear with a more modern, today called traditional model, but a model which is still widely in use, created by United States Federal Government’s National Aeronautics and Space Administration (NASA). It was successfully used for example in 1969 connection with the manned moon landing (Smith, 2014).

Next Image shows the model used by NASA.

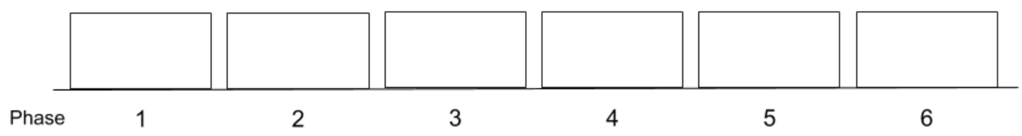

Image 8. NASA-type phased program planning (PPP) system (Rosenberg, Landau, and Mowery. 1992)

NASA calls their sequential development process presented in the Image above as phased programming planning (PPP) system, implemented by NASA's second administrator James Edwin Webb (1906-1992). The numbered phases can be for example concept, feasibility, definition, design, and production, but by modifying the phase names the system fits almost to any development need. The most important guideline in the NASA PPP system is that a new product development project goes through different kinds of logical phases. In these single phase steps, all necessary development requirements are checked, and moving to the next step is allowed only when all necessary requirements are satisfied. NASA’s model is created to minimize the risks, but sometimes problems in one phase can dramatically slow or even stop the entire development process.

More modern “classical sequential model” is also described in Schilling and Hill’s article (Schilling and Hill. 1998), illustrated in the Image below.

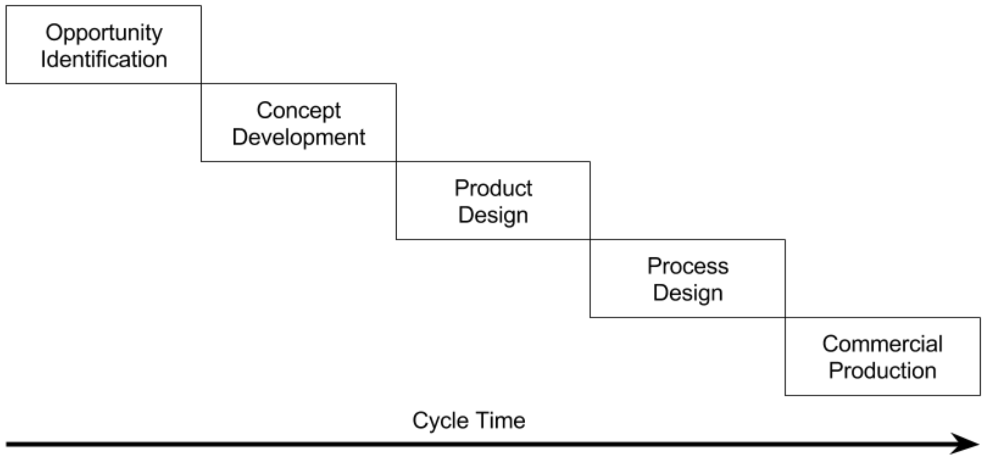

Image 9. Sequential development process (Schilling and Hill. 1998)

Schilling and Hill’s sequential development process, illustrated in the previous Image, continues from one functional group to the next. It has kind of gates where process managers make decisions on whether to proceed to the next gate or step back to the previous one. Alternatively, the decision may even kill the project before moving to the next group box. This sequential model is very similar to NASA’s PPP model; only phase names vary to reflect more modern terms.

Schilling and Hill’s model represents most of the models used with the sequential development process. Similar models can be found widely in use with development processes. Some of them are described in, for example, Duval's business article (Duval, J. 2013), Adam's development article (Adams, D. 2011) and Tuinte's Master's Thesis (Tuinte, R. H. 2011).

3.3 Conceptual Framework

The outcome from this section is the necessary business model tools and concept development methods needed for this study. Conceptual framework subsection also explains how those models and tools are utilized for this Thesis use.

For this Thesis, it is good to use general business model tool to challenge possible weaknesses in the Thesis concept. Also, because this Thesis is not particularly business model creation, the focus is only on some of the blocks in the Alexander Osterwalder's nine building blocks model. These blocks will be used and filled with data from this Thesis, and the outcome is listed in the Concept Proposal section in the second last section of this Thesis. The Image below shows the chosen business model tool slightly adapted from Osterwalder.

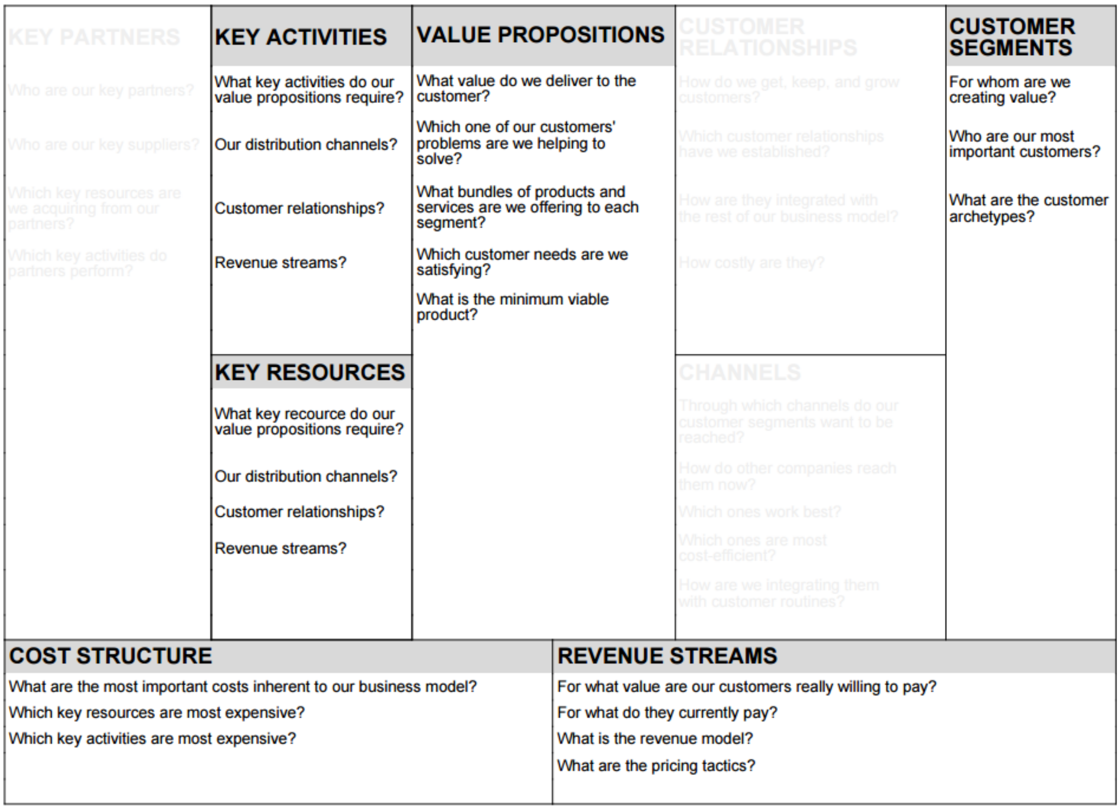

Image 10. Chosen business model tool, adapted from Osterwalder, 2013

In the previous Image, key partners, customer relationships, and channels box have been excluded. Also, some of the hypothesis will be discarded or modified in Concept Proposal section.

In this case, the business model tool needs concept development tool to fulfill whole concept proposal. Introducing chosen concept development model in the following Image.

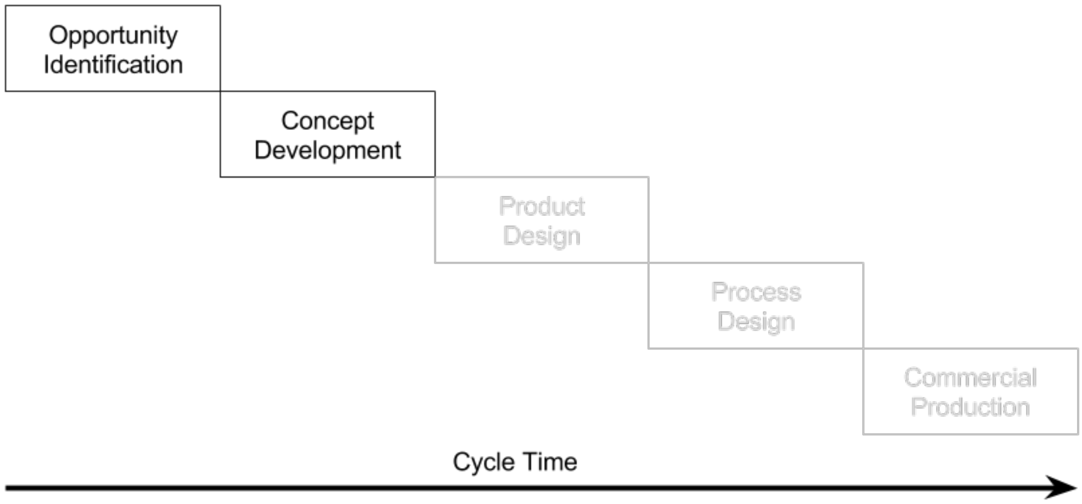

Image 11. Chosen sequential development process adapted from Schilling and Hill, 1998

In the Image above, steps excluded for this Thesis are grayed out. Leaving opportunity identification and concept development steps active. The overlapping developing techniques mentioned at the beginning of development methods has been excluded as there is no need for time-saving developing methods. Moreover, since Schilling and Hill's sequential development process style is widely used and the most recognizable way of development concept like this, it is selected as a model for this work. More accurately, Thesis is splitting these two steps to three similar group boxes with minor modifications for a better fit as illustrated in the next Image.

Image 12. First steps of sequential development process

In the Image above, the first step is to identify opportunity, i.e. detect and simplify the original idea for the process. The second phase is to develop the actual concept as ready as it can be at the beginning of the development. This means creating some level of paper prototype ready for presenting some hands-on experience to support the first step idea, and presenting this paper prototype in the last initial concept phase. When stakeholders are happy with the proposed concept, development can be moved forward to more accurate commercial and technical testing. This commercial and technical testing and all other development steps coming after that are out of the scope of this Thesis.

Next moving into the section of apartment building analyze.

4 Analysis of Apartment Building

This section focuses on creating a base for the neighborhood data center building.

Over 44 percent of Finnish dwellings are in apartment buildings, and also, over 26 percent of all Finnish dwellings are led by housing companies (Statistical Yearbook of Finland. 2014). From these numbers can be estimated that housing companies lead a significant proportion of Finnish apartment buildings. Housing company financial statements are publicly available (Kirjanpitolaki. 1997) and law regulate their actions (Limited Liability Housing Companies Act. 2009). Thanks to these acts, collecting and comparing data from these apartment building housing companies is relatively easy. Therefore, housing companies are also selected for this Thesis as one source.

From a technical point of view, apartment building creates an excellent base for heat re-use. Heat re-users are located next to the heat source, and apartment buildings have commonly centralized heating systems already by default.

The next subsections are to calculate apartment building sizes, energy use, and general upkeep figures. The last subsection is added to include a brief summary of the section results.

4.1 Size of the Building

This subsection includes calculations on the size for a typical Finnish apartment building. Only newish buildings were selected assuming that the Thesis concept can be adapted only to new or newish buildings in Finland. The next two tables below are covering data of the most common sizes of apartment buildings in Finland.

The tables below show the most common sizes of apartment buildings in Finland.

Notes	Number of floors	2010-2014	Unit
Re-calculated	**All in total**	2900	Houses
	1-2 floors	717	Houses
	3-4 floors	972	Houses
	5-6 floors	872	Houses
	7-9 floors	323	Houses
	10+ floors	16	Houses
Excluded	**unknown**	4	Houses

Table 2. Apartment buildings in Finland. Adapted from Official Statistics of Finland (OSF): Buildings and free-time residences.

Analysis of the data from the previous Table continues in the Table below.

Notes	Number of floors	2010-2014	Unit
Re-calculated	**All in total**	6020907	m^2
	1-2 floors	440022	m^2
	3-4 floors	1669573	m^2
	5-6 floors	2484931	m^2
	7-9 floors	1323233	m^2
	10+ floors	103148	m^2
Excluded	**unknown**	1042	m^2

Table 3. Floor area of apartment buildings (m^2) in Finland. Adapted from Official Statistics of Finland (OSF): Buildings and free-time residences.

Calculating from two tables above, a typical apartment building in Finland usually has 3 to 6 floors and the floor area is $2076.2m^2$ ($6020907m^2/2900=2076.2m^2$).

The next step is to resolve average population for this typical apartment building. The next three tables illustrate the surface and living area of a typical Finnish apartment building and Table after those introduces the outcome from these data.

Listing surface and living area of typical Finnish apartment building.

Year	All buildings	Detached houses	Attached houses	Apartment buildings	Other buildings	Living area m² / person
2010	79.5	108.4	71.2	56.5	60.7	39.1
2011	79.8	109	71.2	56.5	61.2	39.4
2012	79.9	109.5	71.3	56.5	61.1	39.6
2013	79.9	109.9	71.3	56.5	60.6	39.8
2014	80	110.8	71.3	56.4	60.7	39.9

Table 4. The surface area per dwelling (m²) with the apartment house type in Finland. Adapted from Official Statistics of Finland (OSF): Dwellings and housing conditions.

Analysis of the data from the previous Table continues in the next Table, Illustrating the surface and living area of a typical Finnish apartment building in Helsinki city.

	Living space per person (m²/person)				
	2010	2011	2012	2013	2014
Helsinki					
In total	34.04	34.05	34.03	33.98	33.9
Number of persons 1	48.4	48.55	48.54	48.6	48.71
Number of persons 2	35.12	35.11	35.08	35.01	35.02
Number of persons 3	27.09	27.05	27.08	27.05	26.99
Number of persons 4	23.57	23.56	23.56	23.54	23.44
Number of persons 5	20.61	20.51	20.51	20.42	20.3
Number of persons 6	17.34	17.1	17.06	17.02	16.88
Number of persons 7+	13.13	12.78	12.88	12.65	12.88

Table 5. Households living area in Helsinki. Persons in households and the living space per person 31.12. Adapted from Helsinki Region Infoshare. Helsingin seudun asuntokuntien pinta-ala. Asuntoväestö ja asumisväljyys henkilöluvun mukaan.

Analysis of the data from the previous Table continues in the next Table. Illustrating surface and living area of typical Finnish apartment building in Helsinki Metropolitan area.

	Living space per person (m²/person)				
	2010	2011	2012	2013	2014
Helsinki Metropolitan Area					
In total	34.72	34.77	34.78	34.76	34.7
Number of persons 1	51	51.18	51.21	51.32	51.43
Number of persons 2	37.49	37.51	37.48	37.44	37.45
Number of persons 3	28.75	28.73	28.77	28.74	28.62
Number of persons 4	25.07	25.06	25.06	25.01	24.94
Number of persons 5	21.92	21.87	21.88	21.85	21.69
Number of persons 6	18.35	18.26	18.22	18.11	18.02
Number of persons 7+	13.92	13.85	13.85	13.63	13.68

Table 6. Households living area in Helsinki Metropolitan Area. Persons in households and the living space per person 31.12. Adapted from Helsinki Region Infoshare. Helsingin seudun asuntokuntien pinta-ala. asuntoväestö ja asumisväljyys henkilöluvun mukaan.

Table data from the above Table is analyzed and used in the next Table.

Presenting the living space outcome in the Table below.

	Living space per person (m²/person)						
	2010	2011	2012	2013	2014	AVG	AVG YR Change
Helsinki	34.04	34.05	34.03	33.98	33.9	34.0	-0.035
Helsinki Metropolitan Area	34.72	34.77	34.78	34.76	34.7	34.7	-0.005
Finland	39.1	39.4	39.6	39.8	39.9	39.6	0.2

Table 7. Households living area, an outcome from the previous three tables.

Since this concept is assumed to work only in the densely populated area, the Helsinki Metropolitan area value is used, leaving other area values to create an understanding of the overall situation in Finland. The outcome is that we have one person per every 34.7 square meters of living space. The calculations also indicate that there is no relevant change taking place for living spaces in Metropolitan area.

Notice the difference in technical terms between living space and building total floor area. Details of this difference are excluded from this Thesis.

The final summary of a typical apartment building analyzes used for this Thesis presented in the following Table.

Name	Figure	Unit
Apartment building size	2076.2	m²
Living area m² / person	34.7	m²
2076.2m²/34.7m²/persons=	60	Persons

Table 8. Typical apartment building in Finland

The previous Table is presenting typical apartment building specifications in Finland. Having apartment building size 2076.2m², living area for the person 34.7 square meters and having approximately 60 persons living in this one typical apartment building.

4.2 General Energy Consumption

A residential apartment uses up to half of the consumed energies into heating, and this heating energy consumption creates the biggest single expense item in a typical apartment building economy (Motiva. 2015). These apartment building energy expenditures come mainly from heat transferring, air ventilation and hot water heating (Motiva. 2015). All these energies create one dependent unit for the energy.

The total energy consumption is also mandatorily calculated for new apartment buildings in Finland as a condition for a building permit, using Finnish term “E-luku” (referred to later on as E-value) (Ympäristöministeriön asetus. 2013). In this Thesis, the total energy consumption is calculated in a slightly different way than the regulated E-value. Because this Thesis investigates the re-use of heat and not exactly a new building energy consumption.

The E-value calculation has certain limit values defined in legislation, and it is mandatory for new builds in Finland. Details of this topic are excluded from this Thesis.

4.2.1 Water Consumption and Hot Water

Using the previously calculated 60 person population in a typical apartment building and multiply this value with average water consumption in apartment buildings in Finland which is 155 liters/person/day (Motiva. 2015; Virta and Pylsy. 2011). This is shown in the Table below.

	liters of water	**%**	**Hot liters (estimates)**	**Cold liters (estimates)**
WC	40	26	0	40
Laundry	20	13	5	15
Kitchen	35	22	17	18
Ablution	60	39	40	20
total water consumption	155	100	62	93

Table 9. Typical apartment building water consumption in Finland. Adapted from Virta and Pylsy, 2011 and Motiva, 2015.

Using the value from the Table above it is to possible evaluate that 40% of the water consumption is hot water (Virta and Pylsy. 2011) (39.1% (Motiva. 2015)). The next Table shows the energy needed to heat up the water.

	Calculation	Value	Unit
Content of water	1l = 1kg	1000	kg
Heat capacity of water	Table value	4.19	joule/gram K
Increase of temperature	5°C water to 55°C This is 50 Kelvin heat increase	50	K
Heating energy	(1000000g*4.19J/g K*50K)/10^6	209.50	MJ
Energy for 1m³ of hot water	1Wh represents 3600Joules, 1kWh = 3.6MJ 1m³ is 1000litres of water	58.19	kWh

Table 10. Theoretical energy needed to heat up the water

Values from the tables above are used for the next Table to calculate hot water energy consumption for a typical Finnish apartment building.

	Calculation	Value	Unit
Consumption of water	155l/1Per/d*60Per*30.42d/month	282906	liters/month
Hot water share	40%	113162.40	liters/month
Energy for 1m³ of hot water	In the previous table	58.19	kWh
Hot water energy total	58.19kWh/m³ *113.1624m³/month 1m³ is 1000liters of water	6584.92	kWh/month

Table 11. Energy needed to heat up water in the typical apartment building

The outcome from the Table above is that there is a need 6.6MWh of energy every month or approximated 79MWh/yr to heat a typical apartment building's hot water. This result amended per square meter, 38kWh/m²/yr, correspond to water heating energy estimate mentioned in Virta and Pylsy's book 35-40kWh/m²/yr very well (Virta and Pylsy. 2011).

4.2.2 Air Ventilation and Heat Transfers

The energy consumption of air ventilation depends on ventilation technology utilized in the building. Heat transfer between indoors and outdoors depends also on the used building methods (Motiva. 2015). This Thesis uses the building heating values of a typical newish apartment. A typical apartment building built in 2010 in Finland consumes approximated 144 kWh/living m²/year (Talokeskus. 2011; Virta and Pylsy. 2011). This value includes energy used to hot water as well. Heating needs vary between different building types; the following Table refers to typically used for heating per cubic energies for this kind of buildings.

	2010	Unit	Converted	Converted unit
High	39	kWh/m³/yr	175.5	kWh/living m²/yr
Low	28	kWh/m³/yr	126	kWh/living m²/yr
AVG	32	kWh/m³/yr	144	kWh/living m²/yr

Table 12. Heat index with conversion to living square meters. Adapted data from Talokeskus, 2011 and conversion value from Virta and Pylsy, 2011 p.20.

In the Table above, heating values in cubic meters are also converted to square meters using conversion value (Virta and Pylsy. 2011) so that it is easier to apply the readings to this Thesis.

The following Table collects energy values from previous tables and calculates the total heating energy value.

	Calculation	Value	Unit
Heating hot water	6584.92kWh/mo*12mo/10^3 12mo=1yr	79.02	MWh/yr
Heating other	heating total minus heating hot water	219.95	MWh/yr
Heating total	144kWh/m²/yr*2076.2m²)/10^3	298.97	MWh/yr

Table 13. Total heating energy usage in the typical apartment building

The Table above shows the calculated energy used for hot water heating annually, total energy needed for an apartment building and calculate other heating energies reducing the hot water energy from total energy need.

4.2.3 Energy Usage Outcome

A typical apartment building in this Thesis consumes 298.97 MWh energy for heating purposes annually. This energy value can be used when calculating the possible data center load for heating this building in the later sections.

4.3 Apartment Buildings's Upkeep Cost Structure

A typical Finnish apartment building spends about 40% of all building running costs on heating, building electricity and water. In a building which is in an economically good condition, this means approximated one euro per maintained square meter (Valtion ympäristöhallinto). The calculated values are shown in the next two tables.

	2010	2011	2012	2013	2014	AVG
	Apartment buildings					
Year of construction	**00-**	**00-**	**00-**	**00-**	**00-**	**00-**
	c/m²/mo	**c/m²/mo**	**c/m²/mo**	**c/m²/mo**	**c/m²/mo**	**c/m²/mo**
Property maintenance costs:						
Personnel expenses	2	2	2	2	2	
Administration	37	38	37	40	43	
Operating and maintenance expenses	51	48	51	57	56	
Outdoor Areas Maintenance	10	10	10	9	6	
Cleaning services	12	15	14	14	14	
Heating	83	78	83	80	78	80.4
Water and wastewater	28	30	29	32	33	30.4
Electricity and gas	18	20	20	22	22	20.4
Waste disposal	12	12	13	14	15	
Non-life insurance	5	5	6	6	6	

Table 14. Apartment building housing companies income statement. Adapted from Official Statistics of Finland (OSF): Asunto-osakeyhtiö tuloslaskelma

Annual costs for a typical apartment building costs are shown in the following Table which uses values from the previous Table.

Calculated values from previous tables presented below.

	Calculation	Value	Unit
Size of the housing company		2076.2	m²
Heating	80.4c/m²/mo*2076.2m²	1669.3	€/mo
Water and waste water	30.4c/m²/mo*2076.2m²	631.2	€/mo
Electricity and gas	20.4c/m²/mo*2076.2m²	423.5	€/mo
Sum		2724.0	€/mo
Sum Annual	2724€/mo*12mo	32688	€/yr

Table 15. Typical apartment building energy annual costs

The upkeep costs of a typical apartment building shown in the Table above will be used in a later part of this Thesis.

4.4 Summary of Key Characteristics of Apartment Building

The section outcome is the building base for the neighborhood data center, as well as the possible energy levels what could be re-used in the concept model. Results can be crystalized into these three values, floorage of the heated apartment building is 2076.2m², and building is using 298.97MWh energy for heating purposes annually, and estimated average cost for apartment building heating is 32688€ per year. Other collected and investigated values can be used in the post-Thesis for more detailed calculations.

5 Apartment Building as a Data Center

This section focuses on using the results from the previous section. Also, start building a data center on top of this apartment building base and examine the implementation of the concept from data center perspective.

As stated at the beginning of this Thesis, an apartment building is not the most common way to build a data center. Because of this, some modifications to the existing techniques must be done. Therefore, the section is split into subsections of power, cooling, hardware, redundancy, security, maintenance, production, environment and location benefits parts, which explains these changes and differences in this concept comparing to the traditional models. The last subsection is added to include a brief summary of the section results.

5.1 Power Usage

In the previous section, there was calculated energy needs for the apartment building. Need is 298.97 MWh energy for heating purposes annually in the typical apartment building.

Because most of the data center consumed energy is transferring to the heat (Minas and Ellison. 2009), can be assumed that the apartment building data center needs to consume approximated the same amount, 298.97MWh/yr of electricity to keep this example building heated up.

In the next table, it is calculated how much server load is needed to create such heat energy.

	Calculation	Value	Unit
Load always on	(298.97MWh/yr)/(8.736MWh/yr) 1kW load always on = 8.736MWh/yr	34.22	kW
IT load PUE 1.50	34.22kW/1.50	22.82	kW

Table 16. Typical IT load creating heat load calculation

The Table above uses power usage effectiveness (PUE) value and load power factor value of 1. PUE value is commonly used in data center industry to indicate power usage efficiency, and in this case, it is used PUE value of 1.5 (Uptime Institute. 2014) to estimate how much of IT load is needed to create this 298.97MWh/yr heat energy.

PUE value is a slightly controversial method to calculate data center efficiency, mainly because of the missing exact rules for calculations (Avelar, Azevedo and French. 2012; Rouse. 2009). In this Thesis, it is just an estimating tool to simplify the results.

Another value used in this typical IT load calculation above is power factor value. The power factor is needed when calculating the real power usage of an alternative current electrical power system (RapidTables.com. 2016). For this purpose, it is used estimation that the power factor value is 1, and it is not affecting to the calculations.

There are now two estimations used for these IT load calculations. IT loads are dynamic values and depend a lot on the actual work the IT load is asked to do. It can also be possible to have 30% of the servers in so-called idling mode and generating less or almost no heat at all (Koomey and Taylor. 2015).

Therefore, it makes no sense try to calculate the precise IT load values. Also from the electricity infrastructure point of view, most often power feed per rack is rounded to the closest standard sized electrical power supply size (International Electrotechnical Commission. 1999). In this case, it is practical to round the value for one CEE red 32A 400VAC connector or two CEE red 16A 400VAC connectors, both providing desired 22kW power feed.

Depending a lot on the used server technology and the IT load functions, the desired 22kW IT load can be two 42U unit racks (see the previous Table of typical IT load creating heat load calculation; Quora. 2011). In the next subsection, it is investigated how this 22kW load transfers into the apartment building heating system.

Energy prices for data centers also depend on a lot on chosen energy production method. The larger the data center operator is, the greater the importance of the electricity price is for the productivity. For this Thesis selected price is a typical price of electricity which would be likely for large consumers such as the apartment house. Annual average prices are shown in the following Table.

2010	2011	2012	2013	2014	Unit
7.28	8.09	7.67	7.61	7.34	snt / kWh

Table 17. Typical electricity prices in Metropolitan Area Finland. Adapted from Energy Authority.

The Table above uses average annual values including electricity cost, transfer cost, but excluding taxes. The example prices are calculated from 20MWh annual consumer to have more accurate data available (Energy Authority. 2016). Typically bigger customers get their electricity cheaper than smaller clients (Sähköinfo Oy. 2010). Using these values above, an average price for years from 2010 to 2014 is 76 euros per MegaWatt hour.

These numbers will bring us to the conclusion that 22kW (1kW load always on = 8.736MWh/yr) IT load with 1.5 PUE and power factor 1 cost to run (22*1.5*1*8.736MWh/yr*76euros) 21909.89 euros/yr.

5.2 Cooling Technology

Without going into not too relevant technical details, one and easiest method to cool down data racks is transferring the heat from servers to IT equipment cooling water (Whitmore. 2014). After this heat transfer, the IT equipment cooling water energy is used to compensate apartment building's heating energy losses, which in nontechnical terms means heating up building's radiators (Motiva Oy. 2013). Moreover, it is used for pre-heating apartment building's hot domestic water line. If technically possible in a specific building, the IT equipment cooling water energy can also be used for non-potable or greywater heating (Miller. 2014).

5.3 Hardware Operations

Working IT equipment, or in data center language, "hardware" is needed to get heating energy coming and keep these previously mentioned racks in full use. As mentioned before in the Power Usage section the IT equipment's energy usage varies a lot. This creates a situation where there is no exact amount of IT equipment which there has to have for this kind of neighborhood data center. So there is need to trust estimations again. If 30% of the servers can be in idle mode (Koomey and Taylor. 2015) and need is at least two full racks of IT load (referring to Power Usage subsection), this means 2.6 full racks of IT equipment. It must also be taken into account that the IT equipment needs maintenance, the equipment has an expected lifetime, and there is always a possibility to have failed hardware components in the data center (Edwards. 2010). Maintenance is discussed in more detail in a later subsection, but here it can be estimated a double amount of IT equipment from 2.6 to 5 racks from the maintenance point of view.

5.3.1 Redundancy of Critical Components

Data centers commonly need redundancy to their power feeds and for other critical components, for example, the main network switches (SAP SE. 2016). In this neighborhood data center concept, redundancy can be thought of more freely than in traditional data center concepts.

It is highly unlikely that this kind of single neighborhood data center operates on their own, so one data center unit small like this can easily reroute to the nearest working data center in case of power or equipment failure. However, there is no obstacle, for example, to have these neighborhood data centers in buildings which are designed to be off the grid buildings (Kaysenmay. 2012), having city power feed just for a backup power feed.

5.4 Services

Data center technologies need human-based services to keep systems up and running, in the following subsections, it is taken a closer look into some of these needed services.

5.4.1 Security Solutions

Security is taken seriously in data center world (Scalet. 2015), and often detailed security plans are not visible to the public. The neighborhood data center concept requires different kind of security planning relying heavily on the technical and physical type of security.

In Finland, there is legislation that all building complexes with more than 1200m² building area need an air-raid shelter (Pelastuslaki 379/2011). It means that a typical Finnish apartment building has one as well.

An air-raid shelter makes an excellent environment for physically safe data center location. All necessary shelter protections levels, which are in this case exactly same as burglary protection, comes from Finnish regulations (Sisäasiainministeriön asetus 506/2011).

The neighborhood data center needs multiple technical security practices to achieve a higher data safety. Some of those are typical for data centers, and some are new or needs heavy modifications to fit this concept. Those technical solutions are excluded from this Thesis.

5.4.2 Maintenance and Operations

As already mentioned in Hardware Operations section that there is a way to reduce IT equipment maintenance needs by multiplying the needed hardware located in the neighborhood data center. Some data centers manufacturers use this method when building modular data centers.

A modular data center model is where data centers, often temporary ones, are built using with sea containers full of data center equipment. These modular container data center blocks have enough backup equipment located in the containers and have these modules virtually service free (AST Modular. 2016; Wikipedia. 2016). This Thesis is using this same modular model in this neighborhood data center concept. However, some roving maintenance technician is likely to be useful to solve technical issues. Several companies offer similar data center maintenance work, and this concept environment does not differ from a technical maintenance point of view from a traditional data center environment. For more hands on figures for maintenance costs, there can be estimated the cost by using existing typical apartment building maintenance costs shown in the Table named “Apartment building housing companies income statement”. The apartment building uses 3488 euros annually to cleaning services. It can be estimated that it is unlikely spend less that this on IT maintenance.

Maintenance is greatly influenced by the maintenance technics and hardware system quality used. Thus, it is not fruitful to go in more into these technical details.

5.5 Cost and Revenue Considerations

This subsection takes to look into cost and revenue factors. Calculating estimates how much this kind of data center can create revenue and what kind of value add-ons could be used to increase incomes.

5.5.1 Production Data

The direct neighborhood data center income comes from the savings in apartment heating costs. In a normal situation that energy would be directly used for heating without data processing. However, usually commercial data centers are producing resellable IT services too (Palo Alto Networks Inc. 2016). These can be for example data storing, data processing and data calculation services. This concept, in particular, would benefit from prioritizing production IT services generating much heat. Also, with physical limitations mentioned in Redundancy of Critical Components section, IT services like data processing, data calculation and fast caching are preferred. Moreover, keeping in mind that to get real saves, it is needed to deduct the energy costs needed to run the data center from the IT services incomes.

It is impossible to calculate accurately how much one rack of servers produces value to their owners. All the processed data have different values to their users and owners, giving an example of “searching for extraterrestrial intelligence”, later used as SETI (SETI@home. 2016), almost valueless data and comparing it, for example, to very valuable an automatic stock trading data calculation (Folger. 2011). To simplify things, typical colocation data center rack rental prices can be used to get a baseline. It can be assumed that data processing income always exceeds typical colocation rack running prices. It is worth noting that this is the main reason the previously mentioned SETI project cannot use commercial data centers to process their data.

In the following Table, estimates for typical rental prices in Finnish colocation data centers are shown.

Company	Rack	Power	Unit	Price	Unit	Time
Creanova Hosting Solutions Ltd, Helsinki Finland	1U	350	W	80	€	Mo
Creanova Hosting Solutions Ltd, Helsinki Finland	2U	500	W	120	€	Mo
Creanova Hosting Solutions Ltd, Helsinki Finland	4U	1000	W	200	€	Mo
Creanova Hosting Solutions Ltd, Helsinki Finland	12U	1500	W	400	€	Mo
Creanova Hosting Solutions Ltd, Helsinki Finland	22U	2000	W	600	€	Mo
Creanova Hosting Solutions Ltd, Helsinki Finland	42U	4000	W	1000	€	Mo
Woima Hosting Oy, Turku Finland	1U	500	W	63	€	Mo
Woima Hosting Oy, Turku Finland	2U	500	W	83	€	Mo
Systec Services, Turku Finland	1U	230	W	90	€	Mo
Systec Services, Turku Finland	2U	250	W	120	€	Mo
Systec Services, Turku Finland	3U	300	W	140	€	Mo
Louhi Net Oy, Espoo Finland	1U	350	W	89	€	Mo
Louhi Net Oy, Espoo Finland	2U	500	W	149	€	Mo
Louhi Net Oy, Espoo Finland	4U	1000	W			
Louhi Net Oy, Espoo Finland	6U	2000	W			
Louhi Net Oy, Espoo Finland	20U	5000	W			
Sigmatic Oy, Helsinki Finland	1U	NA		99	€	Mo
Sigmatic Oy, Helsinki Finland	2U	NA		99	€	Mo
Sigmatic Oy, Helsinki Finland	10U	NA		299	€	Mo
Sigmatic Oy, Helsinki Finland	21U	NA		499	€	Mo

Table 18. Finnish colocation data center rack list prices

Company	Rack	Power	Unit	Price	Unit	Time
Kotisivut.com on Mediam Oy, Espoo Finland	1U	250	W	NA		
Kotisivut.com on Mediam Oy, Espoo Finland	2U	400	W	NA		
Kotisivut.com on Mediam Oy, Espoo Finland	3U	500	W	NA		
Kotisivut.com on Mediam Oy, Espoo Finland	4U	600	W	NA		
Kotisivut.com on Mediam Oy, Espoo Finland	21U	1000-4000	W	NA		
Kotisivut.com on Mediam Oy, Espoo Finland	42U	1000-20000	W	NA		
AVG values	1U	336	W	84	€	Month
AVG values	2U	430	W	114	€	Month
AVG values	22U	3000	W	550	€	Month
AVG values	42U	8333	W	1000	€	Month

Table 18. (Continued from the previous page) Finnish colocation data center rack list prices

The Table above shows that one full rack costs approximately 1000 euros per month in a colocation data center. This value can be used for the neighborhood data center income as well. In the subsection of Hardware Operations is calculated the number of racks needed to be 2.6 pieces. From the billing point of view, it is not possible to calculate available backup IT equipment for income, but instead, a data center can bill from idling IT services (also explained in Hardware Operations section). This would bring a 2600 euro steady income from the 2.6 racks.

5.5.2 Green Computing

If CO²-neutral electricity source is used in neighborhood data center concept, and when this concept re-uses all energy in the data center it will make this concept one of the greenest data center possible to build. This kind of concept is way ahead of its time at the moment, and it would be reasonable to expect that environmentally conscious customer are willing to pay higher service prices for it (Golinska and Kawa. 2015).

5.5.3 Location Benefits

The neighborhood data centers can be located close to the customers, having significantly faster service response times (the technical term is latency), approximated between 5 to even 20 times faster compared to gigantic scale cloud service providers (CloudPing.info. 2016; Kent. 2015).

Faster response times bring possibilities to use more connection critical software and give a possibility to process more valuable data and charge higher service prices (mentioned in Production Data section). Also, this benefit can be used to invest lower performance (cheaper) equipment in the data center when consuming available data processing time inside the data center neither on optical fibers traveling to the customer (Kent. 2015).

It is also psychological benefit or even mandatory from legislation processing client data geographically close to customer's data source (ICO. 2016).

5.6 Summary of Using Apartment Building as a Data Center

Section outcome is that there is now implemented working data center model on the apartment building model introduced in the previous section. These results will now be used for concept proposal.

Summarized key findings from this particular section are;
The apartment building can use 22kW of servers for heating purposes to keep building warm. This amount of servers is consuming electricity approximately 21909.89 euros/yr. Servers can be placed in 5 separate IT equipment racks and cooled with water-cooling methods, transferring heat to apartment building radiators. These racks, in turn, can be located for example to apartment building air raid shelter having IT services also secured from external threats. Using roving maintenance technician with access into this shelter space to maintain the data center when it is needed.

In this section it is also calculated that this amount of service capacity can approximately bring 31200 euro annual income, depending a lot from offered IT services and how much additional green and location value can be charged from the customers.

6 Proposing an Initial Business Concept

This concept proposal section brings together the different parts of the concept and forms one entity. This includes parts of the theoretical business model to run this kind of data center.

In the Conceptual Framework section, Alexander Osterwalder's nine box canvas model chosen to help with business model construction. Next, those highlighted boxes are filled with necessary data collected through this Thesis. The subsection topics following Osterwalder's model (Osterwalder, 2013).

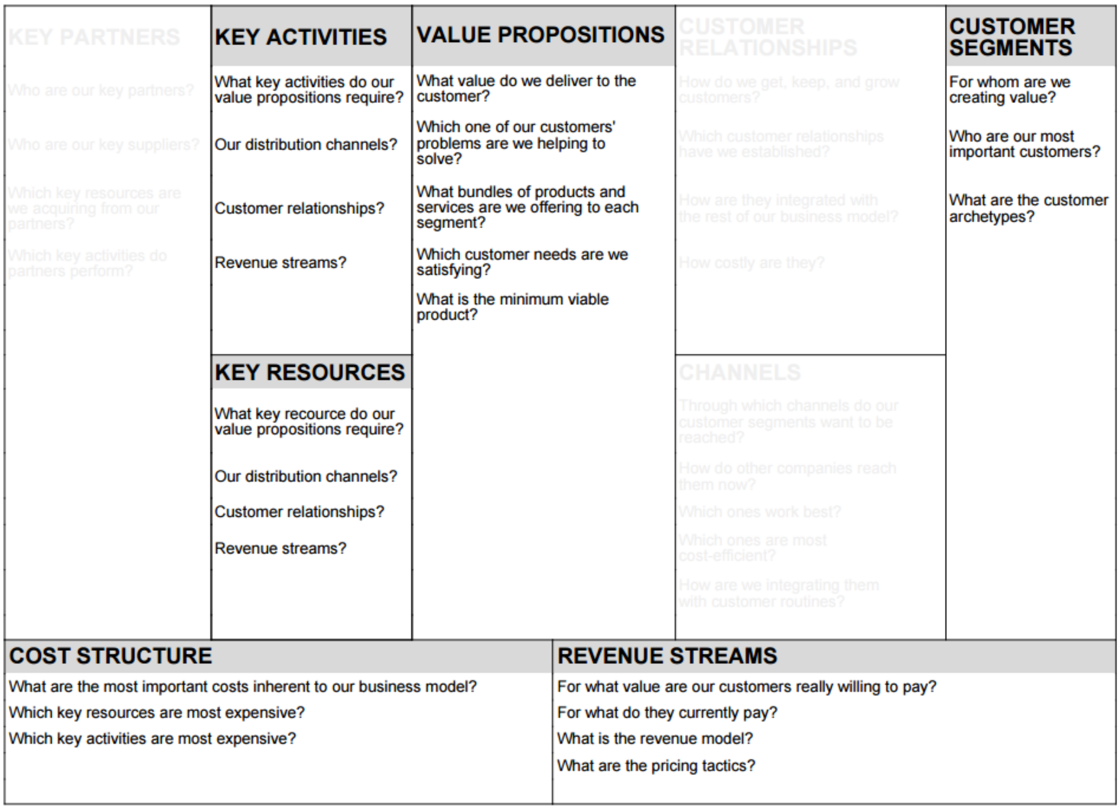

Image 13. Chosen business model tool, adapted from Osterwalder, 2013

6.1 Customer Segment

Customer segmenting looks promising for the neighborhood data center concept. It is possible to focus on customers physically located near the data center, and also involving clients who are critically interested in their carbon footprint. With proper customer segmentation, this concept can stand out from the traditional data center service providers quite easily.

6.2 Value Proposition

The customers are expecting typical data center IT services, such as data-computing, -storing and -rerouting. In practice, the data center IT service can be any digitally processed data.

The data center owner does not have to care about the content of data in their data center. However, like mentioned in earlier sections on heat generation, prioritizing processes generating as much heat as possible in times when heat re-use is most needed. One critical fact around data center business is promises of service quality need to be kept. Interruptions in the IT service are simply not possible without affecting the customer relationship.

It is worth mentioning that this kind of value creation to the client is not unique value creation. In fact, any competitor with data center IT services can offer similar enough value and compete with prices against this concept.

6.3 Key Activities

Key activities are simple; there is a need to have a data center for the customer's use. Key activities do not differ anyhow from a standard data center operation's profile.

One specific item still from concept functioning point of view is that technology solution for local heat re-use has to exist. It is relatively easy to use IT heat load for apartment building heating. In Finland, there has been now a couple of years different kind of prototype apartment buildings already in use where building heating has been created from different kind of sources, for example, geothermal heat and solar panels (Saari, 2011). This kind of mixed heating method is becoming more popular all the time.

The following Image explains the mixed household heating method.

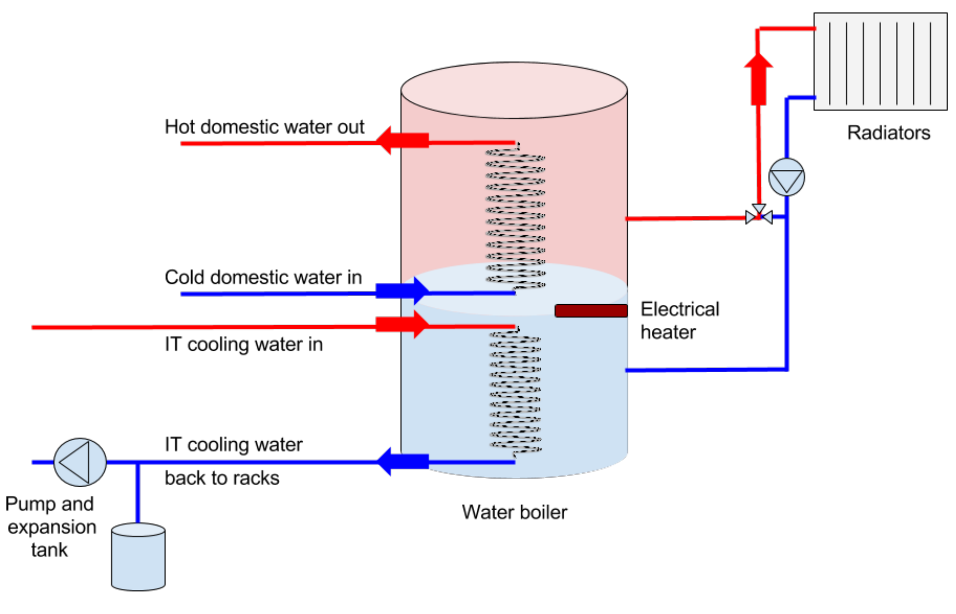

Image 14. Water boiler using additional heat from IT load

The previous Image shows a modern hot water boiler with multiple heating sources added. In this simplified model, IT cooling water heat energy can be used to heat building's hot water systems without direct contact with those water system flows. There is also an electrical heater added to support a possible need for extra energy for example on freezing cold winter days. This kind of boiler layout is just one example of all possible ways to connect heat energy source to the building heating systems.

It does not look like that heat transfer from the IT load for general heating use cause any problems. It is relatively easy to use existing techniques from other buildings with multiple heat sources.

6.4 Key Resources

The neighborhood data center concept needs strong technical and commercial professionals to support running the business and data center customers. It is reasonable to imagine this concept as a part of larger data center concept where these technical and commercial professionals are already in place and keep this neighborhood concept just to be a part of the larger effective data center network.

In the research interview carried out for this Thesis it was pointed out that not everyone is happy to have a data center in their basement (Interview 1. 2016). Apartment building residents are key resources for the neighborhood data center concept. This kind of data center implementation is, however, most likely to be in a new apartment building considering the technical requirements point of view. It is also safe to assume that when people know and choose their house to be in a building with a data center, it is easier to accept the different environment for the living.

Any new building specific risks and safety rules do not differ in severity from the existing apartment building heating methods risks and regulations that much. Also, in normal operations, residents do not have to care or know that there is a data center in their basement.

6.5 Cost and Revenue Considerations

Table below shows all the significant main figures in one view to run a data center in an apartment building environment. There are many more exact items missing, but this layout gives a good overview of how strong the platform is from the economical point of view.

Name	**Value**	**Unit**
Building size	2076.2	m²
Heating energy usage	298.97	MWh/yr
Energy expenses	32688	€/yr
IT load	22	kW
IT load sales	31200	€/yr
IT system electricity usage	288.29	MWh/yr
IT system energy expenses	21910	€/yr
Upkeep costs	3488	€/yr
Investment costs	Not included	€/yr

Table 19. Concept summary figures

The figures in the previous Table show the typical cost of running the data center in an apartment building. However, this calculation need a cost comparison with a same size traditional data center to yield any directly usable information, and this information has been excluded from this Thesis. Still, when using this Table for generalizations and combined with common sense, it can be seen that no direct income comes from changing an apartment building heating method to a data center created heating method.

The actual revenue for the neighborhood data center concept has to originate from a different kind of value creation to the customer. This is income generated by clients who are willing to pay more for being able to live according to their values. Competing data center IT service providers are hard to meet this.

Revenue streams do not differ anyhow from the traditional data center revenue models. The only significant difference already mentioned is the possibility to charge extra for neighborhood data center location and energy re-use benefits.

The proposal summary is presented on the following page.

6.6 Summary of Proposal

A final proposal cannot be the final proposal for this concept, but it is more like a proposal for the next steps of investigation into this kind of opportunity.

From a business model point of view, the easiest way for creating a working business model in the neighborhood data center business case is to have successful, already existing traditional data center business model for the base. After this, this traditional data center business model can be enhanced to address the challenges related to this new concept. For example, according to Mark W. Johnson's White Space definition (Johnson. 2010), this method can be a good start to inspire and continue developing in the right direction model that is already in use to have this kind of neighborhood data center as part of the existing portfolio.

In any case, the business model is needed to finalize in post-Thesis phase before actual product launch.

From concept development point of view, there is a possibility to either go one step back and create more accurate economical feasibility data with revenue data from actual data center business or, relay to these results and go and create an actual prototype in product design step. Both options seem equally reasonable.

From building point of view, a heating apartment building with IT service load do not differ from any other already in use heat source. This kind of multi-heat source heating systems are coming to be more popular, and solutions will come from the general development of energy sources for modern buildings without any input from this data center concept.

7 Discussion and Conclusions

In this section, the results of this Thesis are interpreted from the research and objective point of view.

7.1 Summary (of the whole project)

In the beginning, the main objective was to develop an initial business concept for the neighborhood data-center business idea. Also same time help readers to mind the challenges of the future environmental friendly data center computing. These concept objectives were met, and the results are now waiting for decisions on how it tends to develop further. The models chosen for the conceptual framework worked very well and can be further developed with the steps mentioned in the Thesis results.

Looking at the results analytically, results look alike scratch from the top of the potential concept. It would be good to do more accurate calculations of the concept profitability with non-public revenue data. Several points have also been used as rough assumptions about the concept idea, in part due to the general nature if this Thesis work. This makes it difficult to utilize the results if the assumptions remain without proper grounding.

Generally looking the whole outcome is very positive and gives a great base for developing the concept further. Keeping in mind that concept needs heavy improvement before it can say to be ready for commercialization.

Generally speaking, the concept is innovative, have sustainable features and have possibilities to support itself financially. A brief definition of the results is the famous phrase "definitely maybe".

7.2 Next Steps and Implications

It seems that we are heading into the future where more and more services and the information are digital. This means a great need for new data centers in the future. At the same time, environmental concerns are becoming stronger and are protecting the environment has even been made mandatory for a whole new set of industries.

It is entirely possible that soon the data center environmental demands will require a carbon-neutral operation, or cause changes in the profitability of existing technologies. Therefore, the development of such alternative data centers is significant.

From the point of practical and societal implications, the next steps depend on global climate agreements, local government energy re-use regulations, the willingness of the people to adopt these greener technologies and accept different cost structures of the data centers.

If laws are introduced to force the industry to re-use the energies, this idea of neighborhood data centers may well be one of the probable solutions to handle the situation. On the other hand, it may also be that developing this concept further means that the cost structure may achieve such a level that this kind of data center concept comes in use purely from the commercial perspective.

Another point of view into this Thesis is considering the general production and usage of energy on our planet. If the data centers are made to be carbon-neutral or energies are fully recycled, does it mean that we can build more data centers without concern for the environment? Alternatively, bring us to a known situation where more than one data center professional is already worried. In 1865, technological improvements increased the efficiency with which coal was used, but it led to increased consumption of coal, and did not facilitate the initial situation or discouraged the problems coming from coal usage.

This phenomenon is known as Jevons paradox. In data center world, this Jevons paradox can mean that when data processing is easily available, it is an environmentally friendly, and the use of energy will only grow because it is green. The effect of such development on our planet can lead to unpredictable results. It is good to keep in mind that all different energies in our planet will most likely eventually transform into heat.

Going back into more practical steps, like mentioned in the previous sub-section there is possible to follow different paths forward after this Thesis. The Image below is presenting adapted sequential development process chart from early sections of this Thesis, added with next three steps from Schilling and Hill's model. When this Thesis is ready, the development process is located into initial concept chart box. From this box, next steps can be either backward or forward. If next step is to backward, then the concept is moved back to development phase and one solution is to start a separate feasibility study with nonpublic cost data. While if moving forward to product design step, the concept can be for example developed to prototype level. Collecting accurate primary data from prototype itself.

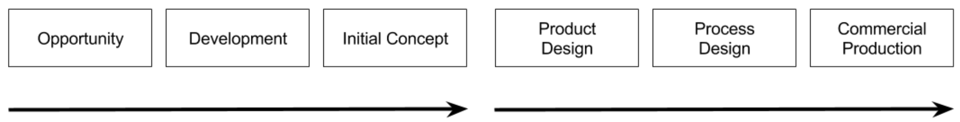

Image 15. The next steps of sequential development process, Adapted from Schilling and Hill. 1998

Image above is also giving steps after product design. Process design can be designing methods for multiplying this single prototype to large scale business. And commercial production could be step when product is launched with expectations of producing positive cash flow for the concept.

7.3 Evaluation

The evaluation subsection looks at the Thesis results and compares them to the expectations before the Thesis completion. In addition, it considers the data limitations in this Thesis.

7.3.1 Outcome Versus Objective

Thesis objectives were to develop an initial business concept for the neighborhood data-center business and help readers to mind the challenges of the future environmental friendly data center computing. The outcome reflects the original objective, although it does not provide all the needed answers. However, further development of the idea sounds reasonable.

A secondary object about environmental challenges depends on a lot of the actions done after this Thesis publication. We all know that global climate agreements, balancing with giving competitive advantages for the competitors, offering more costly greener IT services and making high enough profits are not the easiest tasks to combine. But if we see this Thesis be one drop in the world’s climate bucket, maybe soon we see data centers with 100% energy recycling rate.

7.3.2 Validity and Reliability Considerations

Development works are always inherently unreliable in nature and can be said that this kind of concept study is not the most scientific research. This is mainly due to the fact that there are so many challenging variables in creating the concept and many of the results had to be based on assumptions. Still, the results serve as thought-provoking and ground work a further study for a more accurate concept.

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Appendices

Research Interview (Discussion)

The content of the interview begins on the next page.

Research Interview (Discussion)

Helsinki Metropolia University of Applied Sciences

Master's Thesis

Initial Business Concept for the Neighborhood Data Center

Information about the informant (Interview 1)

Table 1

Interviewer	Jyri Juvalainen
Name (code) of the informant	Informant 1, *Antti Laine*
Position in the case company	Industry sustainability specialist, Ph.D. student from Lappeenranta University of Technology
Date of the interview	29 Jan 2016
Duration of the interview	1h
Document	Field notes of the interview with the informant 1

Field notes (Interview 1)

Table 2

	Topic(s) of the interview	QUESTIONS	FIELD NOTES
1	**Starting point: the interviewee describes his/her experience in view of the topic/problem**	Can you briefly introduce your expertise in the field of sustainable development?	I am an expert of renewable energy sources, I have also worked as waste management designer and with sustainable material management positions. I have a master's degree from technical chemistry and I am currently doing Ph.D. study in Lappeenranta university of technology about sustainable data centers.
		Your expertise in the field of construction in general?	I have fourteen years of on field experience in industrial construction supervisory positions.
2	**Identify strengths/ problems**	How does data centers affect to the future carbon dioxide emissions?	data centers energy consumption will continue to grow strongly, and emissions are set to increase. The highest growth in emissions will come from small inefficient data centers. A good example, in some places, such as in Asia might not even have access to a sufficient green energy for the data centers. This will lead to an increase in data center's carbon footprint. Industry can also mistakenly call their data centers as zero-carbon buildings, although the construction of the building is anything but zero emissions.
		What could today's data centers do better from an environmental perspective?	More stringent requirements for suppliers of plants, for example, Apple begins to require more stringent environmental conditions from their plant suppliers. We also could score the contractor and the supplier's operations from an environmental perspective, use fewer chemicals and recycle operating waste more efficiently.

Table 2 (continued)

2	**Identify strengths/ problems**	Do you believe that decentralization massive data centers to small nano data centers might be sensible from the perspective of sustainable development and the environment?	The relative number of employees is much higher, it is one of the largest carbon footprint creators. Emergency power sources are needed. It can increase an original building's carbon footprint if the building is placed in the data center.
3	**Key concerns**	If the data center become very small, do you believe that the effects of the environment are forgotten completely? In other words, the effects are no longer in the statistics in the same way?	The disappearance in the statistics may be possible, but a positive point of view is to get local renewable energies into use and waste heat straight to apartment building use.
		can you see other problems if the data center become very small?	Data security comes first into my mind.
		How would you feel if on the ground floor of your own home would be a data center?	I would not be delighted if there would be data center in my basement. What about if this adds enthusiasm to break into my house or if the data center downstairs lights battery fire? And all the amount of cables and network construction?
4	**Analysis**	Do you think a society could do something in a totally different way so that data centers emissions would not be a problem at all?	Stricter regulations and licensing conditions, for example, how much carbon dioxide per megawatt shall withstand. Forcing to use renewable energy with building a location in an area where this wind or hydro power is available, backup generator exhaust-gas treatment must be placed on a better level and general placement of the building to the north where a simple air cooling is possible. On the other hand, this may well lead to sharp cost increases.
5	**Best practice**	In general, the industry, are we going into the right direction with sustainable development?	No, we are not, because sustainable material and energy production development should lead to a saving of natural resources. Against our current basic behavior of materials and energy wasteful spending, the starting point must be the savings of materials and energy in spite of their renewable characteristics.
		Do you have a sense of good examples of sustainable development in general industry?	Material recycling in industries, waste has become a raw material. Also cleaning of flue gases and process waters, sulfur has been reduced and the fish have come back to many waterways.
6	**Developme nt needs**	How do you see the future? Any visions which may relate to the data center industry in general?	I am guessing that the data centers may end up in space, unlimited energy and cooling is not a problem. When a certain percentage of the servers is broken, a new satellite can be a sent in the sky. The waterways could be a second location for data centers. For example, the bottom of the sea. Admittedly, environmental permits could pose a problem.

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